High accuracy temperature measurements: Are they worth the investment?

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The authors maintain that high accuracy measurements can lead to dramatic savings in time and dollars.

FIG. 1: In transmitter-to-sensor matching, the sensor is immersed in a precise calibration bath at a stabilized temperature and the transmitter is programmed to capture and match the measurement of that individual sensor.

High accuracy temperature transmitters matched with precision sensors *(Fig. 1)* will cost you a little more initially, but can save time and money in the long run by improving yields and reducing maintenance costs. If you can extend that accuracy to the entire system, the savings can be dramatic.

Accuracy is an uncertain term

Accuracy, in the simplest terms, is a gauge of how much a measurement may vary from the true theoretical temperature value of the process. Broadly speaking, a high-accuracy temperature measurement is better than ±1°C for a span of 200° or less.

The unabridged story is a great deal more complex. Determining accuracy from supplier data sheets can be a test of patience and diligence because vendors use very different ways to compute and portray accuracy specifications. Worse still, the published specifications may not tell the whole story.

While sources of temperature measurement uncertainties are introduced at every level of the measurement, we will concentrate on inaccuracies that may be introduced by the transmitter and the sensor.

Temperature transmitter accuracy

Factors that can contribute to temperature transmitter inaccuracies include:

- *Input accuracy*—Uncertainty of the measurement after conversion through the transmitter's analog to digital converter.
- *Output accuracy or accuracy*—Uncertainty of the output after the signal is converted from digital to analog (includes input accuracy).
- *Resolution*—The smallest change that can be detected in a measurement. It's listed as a percent of span or as a number of bits.
- *Linearity*—Amount of deviation from a straight line between zero and full scale input.
- *Load effect*—Deviation caused by the load on the output.
- *Line voltage effect*—How power supply variation affects the measurement.
- *Cold junction or reference junction compensation*—(Applies to thermocouples [T/Cs] only). The uncertainty a transmitter adds when compensating for input voltage differences caused by temperature fluctuations at its T/C input terminals.
- *Repeatability*—Ability of the unit to generate the same output value for the same input for consecutive measurements under the same operating conditions.
- *Ambient temperature effect*—Deviations caused by changes in the air temperature surrounding the unit.
- *EMI/RFI effect*—Deviations caused by electrical noise or interference.
- *Sensor lead resistance effect*—Deviations caused by the resistance of the leads; varies with sensor type and lead length.

When doing accuracy comparisons, keep in mind that some vendors use the term *linearity* in place of accuracy. Others will state that the accuracy specification includes linearity and repeatability, and assumes specified ambient temperature conditions. Still other specs are stated in terms of a selected temperature range, temperature reading, or measurement span. Just be sure to read the fine print so that you can properly determine the accuracy of a given transmitter under the conditions it will operate in your application.

While all of the factors noted above should at least be considered, there are ways

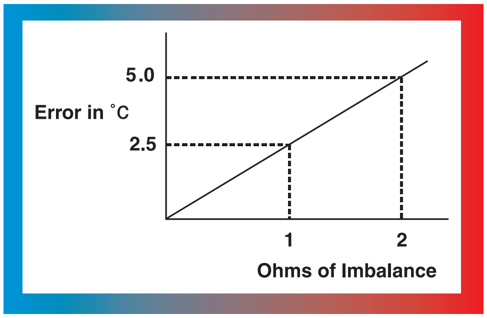

FIG. 2: Every ohm of imbalance in an RTD (100 ohm, Pt3850) sensor's lead wires results in as much as 2.5°C measurement error.

to simplify the comparison process. Take, for instance, a transmitter with an input accuracy of ±0.1°C, an output accuracy of ±0.03% of input span + input accuracy, an ambient temperature effect of ±0.015% of span per °C change +0.001% of ohm reading for RTDs, and a stability of ±0.1% of span per year. Assume that the transmitter is used with a Pt100 RTD with alpha of 0.00385. Further assume that the temperature supplier has included linearity and repeatability in its input accuracy spec.

If the transmitter is calibrated for a 0-100°C span at an ambient of 23°C, the ambient temperature effect at 50°C will be:

$$[(0.00015 \times 100) \times (50°C-23°C)] + (0.00001 \times 119.4 \text{ ohms}) = \pm 0.406°C$$

Adding this to the output accuracy gives the total accuracy:

$$[0.0003 \times (100°C)] + 0.1°C + 0.406°C = \pm 0.536°C, \text{ the worst case error.}$$

In addition, we can expect the output to vary by [(100°C x .001)/year] = ±0.1°C/year.

Temperature sensors and accuracy

Your temperature system supplier should be able to recommend the best sensor for your application. But, in general, an RTD will give you a more accurate, stable temperature measurement than a T/C, provided the somewhat more fragile RTD can withstand the environment.

An RTD or T/C output will change due to temperature cycling, temperature swings, corrosion, lead wires, moisture, and contamination. Two- and 3-wire RTDs are susceptible to lead wire imbalances. Only a 4-wire RTD will give true lead wire compensation when it is used with a transmitter that has a 4-wire input (not just a terminal for the fourth wire).

A 4-wire RTD is the best choice

Every ohm of imbalance in an RTD's lead wires results in as much as 2.5°C measurement error (*Fig. 2*) . Causes of imbalances are: terminal block corrosion, connector corrosion, extension wire splices, manufacturing variance of wires, loose connections, lead length differences, changing lead wire gauge, and work hardening from bending.

A 2-wire RTD doesn't compensate for lead wire length or resistance differences. A 3-wire will compensate for lead wire length if each lead is exactly the same resistance, but will not compensate for differences in lead resistance. A 4-wire RTD (*Fig. 3*) used with a temperature transmitter that accepts a *true* 4-wire RTD input compensates for unequal lead lengths and lead resistance differences.

An intelligent temperature transmitter provides a constant current source to the outer leads of a 4-wire RTD. The voltage drop is measured across the inner leads, which is a high impedance loop. There is virtually no current flow in the voltage loop, so voltage is directly proportional to resistance. Lead resistance is ignored.

As long as the resistance value of the RTD plus corrosion and wire resistance is less than 2000 Ω (typically), you will have the most accurate measurement available from an RTD. A 4-wire RTD is usually only about a dollar more than a 3-wire. You can use junction boxes and terminals without worrying about corrosion. Less expensive smaller gauge wire can be run without concern for added resistance.

What's wrong with direct wiring?

You've chosen the right sensor and you just figured out how to save some money. Why not forget about using a transmitter and run the sensor wire all the way back to the control room? Not only will this method compromise accuracy, it will most likely cost you more in the long run.

Direct wiring transmits the low-level sensor output over sensor extension wires to a control system. Transmitters amplify and condition the signal, and transmit it over a twisted wire pair to the control room.

Sensor extension wires are not only fragile, but cost about three times more than common shielded copper wire used for the 4-20 mA output of a transmitter. Conduit and wire costs can easily be more than the cost of a transmitter, especially with long sensor runs. If you are considering switching to transmitters in an existing installation, you can run the 4-20 mA output over the in-place sensor extension wires. This saves time and money by avoiding a new wire run.

Today's microprocessor-based temperature transmitters have universal inputs and ranges, plus diagnostic capabilities that save precious maintenance time. They continually monitor the sensor and send the output upscale or downscale should a sensor wire break or stop sending a signal. Specific fault messages on an integral display can save the technician from needless troubleshooting or from having to replace the sensor.

Noise interference can have a significant effect on accuracy. Using direct wiring subjects the high impedance, low-level sensor signals to the harmful effects of RFI/EMI.

A temperature transmitter filters out RFI/EMI noise and converts the low-level signal to a high-level 4-20 mA signal in the field. The low-impedance, 4-20 mA signal is hardy enough to hold up over long distances.

PLCs and DCSs measure readings over the entire (very wide) range of a sensor. Transmitters can be calibrated to any range within a sensor's overall capabilities for far more accurate measurements. RTDs and T/Cs are nonlinear elements. Some intelligent transmitters use up to 128 points of linearization for a precise temperature calculation.

Sensor matching improves accuracy

Some intelligent transmitters provide methods of trimming the input to a particular temperature sensor. The sensor is immersed in a precise calibration bath at a stabilized temperature and the transmitter is programmed to capture the output of the sensor (*Fig. 1*). By capturing two or three data points from the sensor, the transmitter will compensate for the deviations of that sensor from the standard curve (*Fig. 4*).

Another method of calibration uses the Callendar-Van Dusen equation (a method of approximating the resistance-to-temperature relationship for a particular sensor). Most temperature sensor vendors can provide constants for each RTD. These constants are then programmed into a transmitter that accommodates the equation to correct for the sensor's divergence from the standard curve.

RTDs are available with different accuracy ratings based on DIN standards specified at 0°C. A Grade "B" RTD will provide accuracy of ±0.12 Ω at 0°C. Grade "A" is ±0.06%. Significantly more costly are the ±0.04% ⅓ DIN high accuracy RTD and the ±0.01% ⅓ DIN precision RTD. Using a 1000 Ω RTD rather than a 100 Ω will also give better measurement resolution, as each degree change in temperature results in a resistance change ten times greater than that of a 100 Ω RTD. Should your application need a T/C, you can expect a calibrated system accuracy of around ±1°F. A calibrated system with a 1000 Ω platinum 0.06% RTD can be as accurate as ±0.075% of span.

Using the digital output from a smart transmitter rather than an analog output will yield higher accuracy. Reading data directly from a digital signal eliminates the error associated with the D/A converter. Transmitters with digital outputs will often list accuracy specs for the analog output and the digital output separately.

A little about stability

Whereas accuracy is the level of uncertainty of a transmitter's or sensor's output at a given time, stability is the uncertainty of a transmitter's or sensor's output over a period of time. Stability (usually specified as a percent of temperature span per year) will help you tell how often your system will need routine calibration. The temperature sensor is the biggest source of error and should be chosen carefully. Typically, the output of a T/C may drift far more than the transmitter because it is more susceptible to environmental changes.

Total system accuracy

It is important to remember that transmitter and sensor accuracy ratings are just

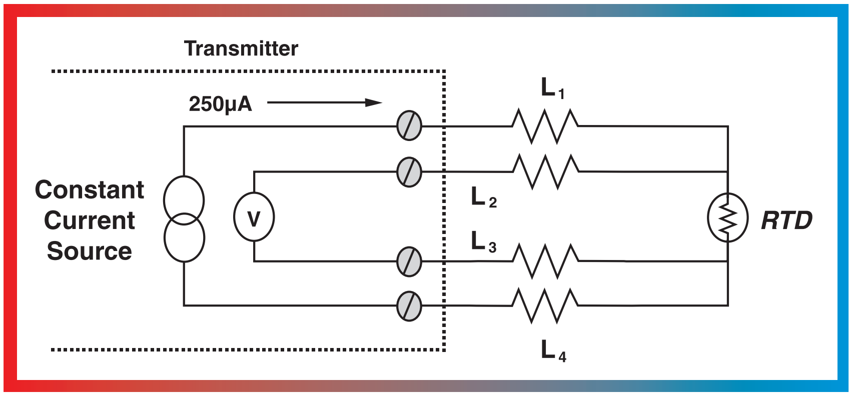

FIG. 3 (top): A 4-wire RTD used with a temperature transmitter that accepts "true" 4-wire RTD inputs will compensate for unequal lead lengths and lead resistance differences. (bottom): A good example of this type of transmitter is the High Accuracy Universal Temperature Transmitter From Moore Industries-International.

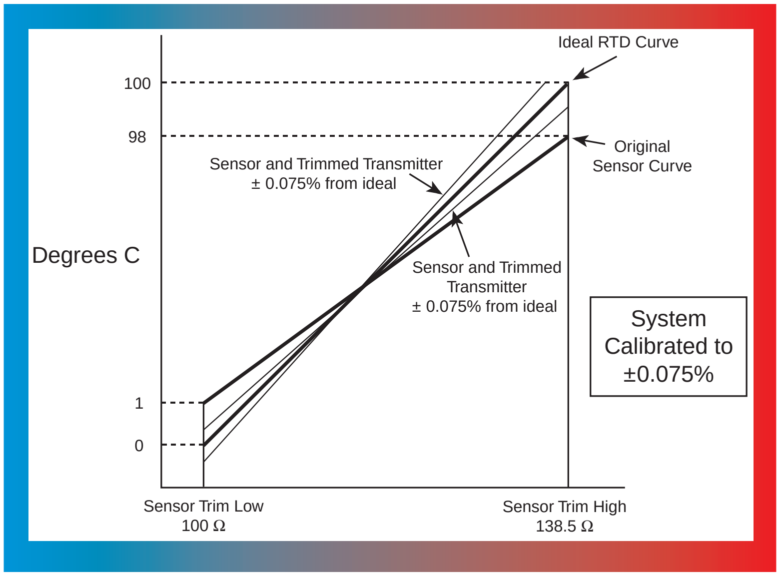

FIG. 4: Capturing two or three data points allows compensation for the sensor's deviation from the standard curve.

part of the story. Total temperature system accuracy is actually determined by adding the accuracy rating of the sensor to the accuracy of the transmitter. Also influencing accuracy is the equipment used to calibrate the measurement loop. The accuracy of a measurement loop is dependent upon the equipment (such as the instrument calibrator) used to perform calibrations. Test equipment should provide a 3:1 accuracy ratio, where the test device is rated at least three times more accurate than the instrument under calibration. Equipment should be traceable to an accredited metrology institute such as NIST (National Institute of Standards & Technology). Calibration standards ANSI/NCSLZ540-1 (derived from MIL-STD 45662A, which is now obsolete) or ISO 10012-1 should be followed to ensure proper transmitter calibration. Without traceability and adherence to approved calibration procedures, you cannot be certain that your temperature measurement is accurate. Some temperature systems vendors, particularly those that supply transmitters and sensors as a unit, will provide NIST-traceable calibration for the entire system, so you can have confidence the equipment being supplied meets their published specifications.

Your return on investment

The appropriate sensor and intelligent temperature transmitter will give you a reliable measurement with minimal maintenance. A precise measurement, whether it's temperature, pressure, flow or level, will never hurt and will probably benefit your process. The best controller in the world can never make up for inaccuracy at the sensor level, so do the math, choose the sensor and transmitter carefully, and reap the benefits.

About the authors

Lori Risse and Greg Vonada are part of Moore Industries' STAR Team, the company's group of applications and customer service engineers. Lori and Greg specialize in specifying and applying temperature transmitters, sensors, and associated instrumentation.

For more information...

The authors, Lori Risse and Greg Vonada, will be available to answer any questions you may have about this article. They can be reached at (818) 894-7111 during normal business hours.